Development of a Knowledge-Based Energy Damage Model for Evaluating Industrialised Building Systems (IBS) Occupational Health and Safety (OHS) Risk

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis/project is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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ABSTRACT

Malaysia's construction industry has been long considered hazardous, owing to its poor health and safety record. It is proposed that one of the ways to improve safety and health in the construction industry is through the implementation of 'off-site' systems, commonly termed 'industrialised building systems (IBS)' in Malaysia, which require fewer workers on-site. This is deemed safer, based on the risk concept of reduced exposure; however, no method yet exists for determining the relative safety of various construction methods, including IBS.

This thesis presents a comparative evaluation of the occupational health and safety (OHS) risk presented by different construction approaches, namely IBS and traditional methods. The evaluation involved developing a model based on the concept of 'argumentation theory', which helps construction designers integrate the management of OHS risk into the design process. In addition, an 'energy damage model' was used as an underpinning framework.

Development of the model was achieved through three phases. Phase I involved collection of data on the activities involved in the construction process and their associated OHS risks, derived from five different case studies, field observation and interviews. Knowledge on design aspects that have the potential to impact on OHS was obtained from document analysis. Using the knowledge obtained in Phase I, a model was developed in the form of argument trees (Phase II), which represent a reasoning template with regard to options available to designers when they make judgements about aspects of their designs. Inferences from these aspects eventually determined the magnitude of the damaging energies for every activity involved. Finally, the model was validated by panels of experts (Phase III), and revisions and amendments were made to the model accordingly.

The model provides a means of evaluating OHS risk among construction workers, which could help designers understand the extent to which their design decisions may impact on OHS and thereby assist them to reduce the risk to an acceptable level. The development of the risk assessment model represents structured knowledge that designers can draw on when making judgments about OHS risks, in the form of argument trees. The model was categorized into several damaging energies, which provides a way to evaluate the risk from start to finish.

The research revealed that different approaches/methods of construction projects carried a different level of energy damage, depending on how the activities were carried out. A study of the way in which the risks change from one construction process to another shows that there is a difference in the profile of OHS risk between IBS construction and traditional methods. For example, the potential gravitational damaging energy for certain activities in the in-situ concrete and masonry method can be removed or reduced by the use of IBS/off-site methods such as the wall panel system and the panellised system. This is compatible

with other researchers' claims that IBS/off-site is safer and carries significantly less risk in traditional construction.

This thesis contributes to knowledge by suggesting options available to product and process designers that allow them to assess the extent to which their design decisions reduce OHS risk in construction, and offering a more rigorous comparison of the OHS risks in IBS and traditional approaches. It is anticipated that the model may provide a way for designers to integrate process knowledge and awareness of safety and OHS risk variables into design to eliminate or reduce hazards in construction.

Keywords: IBS, OHS in construction, knowledge-based energy damage model, off-site construction

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LIST OF ABBREVIATIONS

BOWEC	Building Operation of Work Engineering and Construction
CIDB	Construction Industry Development Board
CIMP	Construction Industry Master Plan
DOSH	Department of Occupational Safety and Health
FMA	Factory and Machinery Act
IBS	Industrialised Building Systems
KBS	Knowledge-Based Systems
MMC	Modern Method of Construction
OHS	Occupational Heath and Safety
OSHA	Occupational Safety and Health Act
SOCSO	Social Security Organization
TAS	Toulmin's Argument Structure
ToolSHeD	Tool for Safety and Health in Design

1 INTRODUCTION

1.1 Introduction

Malaysia's construction industry has been long described as a dangerous industry, in view of its poor health and safety performance. One initiative of the Malaysian government to address occupational health and safety (OHS) in construction is the widespread adoption of Industrialized Building Systems (IBS), commonly termed 'offsite' construction. An IBS approach is commonly deemed to be safer than conventional construction because it changes the nature of the construction process, and requires fewer workers onsite. This assumption is based on the risk concept of reduced exposure to hazards; however, no method yet exists for determining the relative safety of various construction methods, including IBS, compared to traditional in-situ methods. This study explores the impact of IBS on construction workers' safety and health by a thorough investigation of the activities and associated risks in IBS and traditional construction, with the aim of providing a comparative evaluation of the OHS risks involved in different construction approaches.

This introductory chapter presents the context of the research, including the aims and objectives. It outlines the research methodology, and describes the structure of the thesis.

1.2 Research context

1.2.1 Malaysia's construction industry accident rates

The Malaysian construction industry plays a significant role in the development and growth of the country's domestic economy, generating further demands for construction activities (Abdullah & Wern, 2011; Hamid, Majid, & Singh, 2008; Seyyed Shahab Hosseinian, 2012). However, the industry has earned the reputation of being a highly hazardous industry due to its high rates of accidents and fatalities (Abdullah & Wern, 2011; Seyyed Shahab Hosseinian, 2012). There is therefore an urgent need to improve health and safety performance of Malaysia's construction industry .

Accident statistics for the Malaysian construction industry, as reported in the Social Security Organization (SOCSO) Annual Report, are too high (Foo, 2005; SOCSO, 2000, 2009). The most recent figures produced by the Department of Occupational Safety and Health (DOSH) reveal that twenty-two (22) out of sixty-six (66) fatality cases were attributed to the construction industry (DOSH, 2013). These reports, as explained in section 2.1, provide clear evidence that the industry is one of the critical sectors in need of a significant and rapid overhaul to its current site safety practices (Hamid et al., 2008). This thesis suggests that understanding the hazards within different construction processes, such as IBS, will provide critial new information that can help improve construction health and safety.

1.2.2 The relative safety of IBS

Of the many initiatives that could be implemented to improve OHS performance, offsite construction (commonly termed IBS in Malaysia) has been suggested as a replacement to traditional construction methods (CIDB, n.d., 2007). The Malaysian government is actively promoting the adoption of IBS and encouraging a paradigm shift in the construction process, from a traditional to an industrialized approach. This is demonstrated by the promulgation of the Construction Industry Master Plan (CIMP) 2006-2015 (CIDB, 2007), which specifically mentions IBS and its implementation through IBS Roadmaps.

The nature of activities in IBS differs from that of traditional processes. IBS is an industrialized process in which components of a building are conceived, planned, and fabricated, and then transported to and erected on site (Junid, 1986). Claims have been made that IBS, or more specifically offsite construction, can reduce site accidents (Gibb, 1999; Toole & Gambatese, 2008; Gangolells, Casals, Forcada, Roca, & Fuertes, 2010; Mckay, 2010). However, the extent of this impact on safety and health in construction is still unclear, as there are no current systems to comparatively assess OHS risks in different construction processes. McKay (2012) has identified the OHS risks of both onsite and the offsite processes, but presents a static assessment that lists hazards of specific processes, rather than comparing the extent of the risks of the various processes. There is therefore a need for a robust dynamic method for comparing different construction processes, such as IBS and traditional approaches, to determine the relative safety and health performance of these

processes. Further, the context of the Malaysian construction industry needs to be superimposed on this methodology as current work is centred on developed industries such as the UK/Europe, US and Australia.

1.2.3 The concept of 'designing for safety' and IBS

The benefits of IBS can be better understood if viewed as a change from the traditional design of construction products and processes. This is because, moving from traditional construction methods to IBS changes the process, and the changing design decisions may affect the significance of a particular safety risk. Different construction processes possess different hazards and risks. Therefore, by integrating construction process knowledge into design process, hazards and risks during construction can be eliminated or reduced through process change. The decision to use a particular construction method happens at the design stage, when designers put forward the construction method that offers potential OHS risk reduction throughout the construction process. This is in line with the concept of 'designing for safety', where all safety aspects are considered during the design process, with the aim of reducing or eliminating hazards during construction (Behm, 2005). The 'designing for safety' concept is implicit in product design, therefore many studies relating to 'designing for safety' imply product design, rather than process design. This study focuses on process design, which provides options for designers on how to build the product, thus adding value to the current body of knowledge.

In Malaysia, initiatives for addressing safety in the design phase are defined in the Master Plan for Occupational Safety and Health in Construction Industry 2005-2010(CIDB, n.d.) and Occupational Safety & Health Master Plan for Malaysia 2015 (Ministry of Human Resources, n.d.). Some of the positive recommended actions addressing OHS are related to 'designing for construction safety' and include education in OHS concepts, and providing guidelines for clients to have safety and health design checks put in place before construction (CIDB, n.d.; Ministry of Human Resources, n.d.). However, it is doubtful that Malaysian construction designers adequately understand how to identify, assess and control OHS risks in their designs. This assumption is based on the 'nature of the job/responsibility', in which designers are usually not involved in or responsible for OHS. Therefore, it is vital to have a

structure that can assist Malaysian construction designers to better integrate OHS risk management into the design process.

In order to evaluate and compare the OHS risks throughout traditional and IBS construction processes, a structured method incorporating specialist OHS knowledge and guidance is required. An 'argumentation theory model' (Toulmin, 1958; as cited in Yearwood & Stranieri, 2006) building on the work of Cooke, Lingard, Blismas, & Stranieri (2008) is proposed as a method to integrate the management of occupational health and safety risk into the design process. Cooke et al.'s work was developed from structured knowledge in the context of uncertainty and discretionary decision making, involving expert reasoning regarding design impacts on OHS risk represented by 'argument trees' (Cooke et al., 2008). Their model explored the use of argumentation theory in product design, which focused on the implementation of physical aspects of the design. This thesis presents the development of a process-centric model that consists of a series of argument trees for best practice reasoning that can be used by designers or decision makers when examining the OHS risks posed in different construction processes. The argument trees consist of knowledge which were developed by focusing on the process involved to build a product in various construction processes. The model provides consideration of product and process design concurrently, thus contributing to the body of knowledge. In addition to Cooke et al.'s model, an 'energy damage model' (Viner, 1991) is used as an underpinning framework for developing the present model. The development of this model suggests options for the decisions that can be made by product and process designers, in such a way as to assess the extent to which their design decisions mitigate the OHS risk in construction, and thereby offering a more rigorous relative comparison of OHS risks between IBS and traditional approaches.

1.3 Research purposes

This section outlines the research question and objectives, with a description of the scope and limitations of the research.

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